Azimuthal asymmetries in Deeply Virtual Compton Scattering on an unpolarized proton target

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Preliminary results on azimuthal asymmetries in leptoproduction of real photons on an unpolarized hydrogen target measured at the HERMES experiment are presented [1]. The analysis of data taken with different beam charges and helicities allows for a simultaneous extraction of asymmetries originating from the interference term and the squared DVCS amplitude. Sizeable asymmetry amplitudes for the first cosine moment of the beam-charge asymmetry and the first sine moment of the beam-spin asymmetry have been found. The results are compared to different theoretical calculations.

1 Introduction

Hard exclusive leptoproduction of real photons on nucleons (Deeply Virtual Compton Scattering, DVCS) can be described using Generalized Parton Distributions (GPDs) [2, 3]. These subsume both Parton Distribution Functions and Form Factors and thus provide a 3-dimensional picture of the nucleon. They also offer a way to access the total angular momentum carried by the partons in the nucleon [4].

The DVCS process interferes with the Bethe-Heitler (BH) process, because both have the same final state consisting of the scattered beam lepton, the recoiling proton and a real photon. The latter is radiated from the struck quark in the case of DVCS and from the lepton in the BH process. This leads to three amplitudes squared entering into the cross section for exclusive leptoproduction of real photons, namely the squared DVCS amplitude $|\mathcal{T}_{\mathrm{DVCS}}|^2$, the squared BH amplitude $|\mathcal{T}_{\mathrm{BH}}|^2$ and an interference term $\mathcal{I}$ [5, 6]:

$$\frac{d\sigma}{dx_B dQ^2 dt d\phi} = \frac{\alpha^3 x_B y}{16\pi^2 Q^2 e^3} \frac{2\pi y}{Q^2} \frac{|\mathcal{T}_{\mathrm{DVCS}}|^2 + |\mathcal{T}_{\mathrm{BH}}|^2 + \mathcal{I}}{\sqrt{1 + 4x_B^2 M_N^2/Q^2}}.$$

The kinematic quantities in this equation are the Bjorken scaling variable x_{B}, the squared four-momentum transfer mediated by the virtual photon Q^2, the squared four-momentum transfer to the nucleon t and the azimuthal angle ϕ, defined as the angle between the lepton scattering plane and the photon production plane. The BH amplitude gives the largest contribution at the HERMES kinematics and is calculable in Quantum Electrodynamics. However, the extraction of different asymmetries with respect to the beam charge and/or beam helicity allows to access the suppressed terms.

The cross section for a longitudinally polarized lepton beam scattered off an unpolarized proton target σ_{LU} can be related to the unpolarized cross section σ_{UU} by:

$$\sigma_{\mathrm{LU}}(\phi; P_{\mathrm{l}}, e_{\mathrm{l}}) = \sigma_{\mathrm{UU}}(\phi) \cdot \left\{1 + P_{\mathrm{l}} A_{\mathrm{LU}}^{\mathrm{DVCS}}(\phi) + e_{\mathrm{l}} P_{\mathrm{l}} A_{\mathrm{LU}}^{\mathcal{I}}(\phi) + e_{\mathrm{l}} A_{\mathrm{C}}(\phi)\right\},$$

where $e_{\mathrm{l}}(P_{\mathrm{l}})$ denotes the beam charge (polarization). This defines the charge (in)dependent beam spin asymmetry (BSA) $A_{\mathrm{LU}}^{\mathcal{I}}$ ($A_{\mathrm{LU}}^{\mathrm{DVCS}}$) and the beam charge asymmetry (BCA) A_{C}. In the analysis only effective asymmetry amplitudes can be extracted, which include ϕ-dependencies from the BH propagators and the unpolarized cross section.

The above defined asymmetries have been expanded in ϕ:

$$
\begin{aligned}
A_{\mathrm{C}} &= c_{0,\mathrm{C}} + s_{1,\mathrm{C}} sin\phi + c_{1,\mathrm{C}} cos(\phi) + c_{2,\mathrm{C}} cos(2\phi) + c_{3,\mathrm{C}} cos(3\phi), \\
A_{\mathrm{LU}}^{\mathrm{DVCS}} &= c_{0,\mathrm{LU}}^{\mathrm{DVCS}} + s_{1,\mathrm{LU}}^{\mathrm{DVCS}} sin\phi + c_{1,\mathrm{LU}}^{\mathrm{DVCS}} cos(\phi) + s_{2,\mathrm{LU}}^{\mathrm{DVCS}} sin(2\phi), \\
A_{\mathrm{LU}}^{\mathcal{I}} &= c_{0,\mathrm{LU}}^{\mathcal{I}} + s_{1,\mathrm{LU}}^{\mathcal{I}} sin\phi + c_{1,\mathrm{LU}}^{\mathcal{I}} cos(\phi) + s_{2,\mathrm{LU}}^{\mathcal{I}} sin(2\phi),
\end{aligned}
$$

where the $sin\phi$ ($cos\phi$) term in the BCA (BSAs) and the $sin2\phi$ term in the charge-independent BSA have been added as a consistency check. By combining the data taken with different beam charges and helicities, the amplitudes have been fit simultaneously using a Maximum Likelihood method, which is described in detail in [7].

2 Data analysis

The data has been taken at the HERMES experiment [8] located at the HERA storage ring at DESY. The longitudinally polarized electron (positron) beam of 27.6 GeV energy was used to scatter off a polarized or unpolarized internal hydrogen gas target. Exclusive events have been identified by requiring the detection of exactly one lepton with the same charge as the beam and $Q^2 > 1$ GeV^2 and of exactly one photon. In addition, as the recoiling proton has not been detected, the missing mass M_{x} was required to match the proton mass within the resolution of the spectrometer. With these cuts it is not possible to distinguish the elastic DVCS/BH events from the associated processes, where the nucleon in the final state is excited to a resonant state. Monte Carlo (MC) simulations estimate its contribution to about 12%, which is taken as part of the signal. The main background contribution with about 3% is originating from the semi-inclusive π^0 production and is corrected for. The exclusive π^0 production is estimated to be less than 0.5%.

The systematic uncertainties are obtained from a MC simulation estimating the effects of limited acceptance, smearing, finite bin-width and the alignment of the detectors with respect to the beam. Other sources are the background corrections and a shift of the position of the exclusive missing mass peak between the data taken with different beam charges.

3 Results

The first four rows of figure 1 represent different cosine amplitudes of the BCA, whereas the last row displays the fractional contributions of the associated process. In the first column the integrated result is shown, in the other columns the amplitudes are binned in $-t$, x_{B} and Q^2. The error bars represent the statistical and the bands the systematic uncertainty. The magnitudes of the first two cosine moments $A_{\mathrm{C}}^{cos0\phi}$ and $A_{\mathrm{C}}^{cos\phi}$ increase with increasing $-t$, while having opposite signs as theoretically expected. Both relate in HERMES kinematics to the real part of the GPD H, but the constant term is suppressed relative to the first moment. The second cosine moment appears in twist-three approximation and is found to be compatible with zero like the third cosine moment, which is related to gluonic GPDs.

The charge-independent BSA moments are found to be compatible with zero (not shown, see [1]). On the contrary, the first sine moment $A_{\mathrm{LU,I}}^{sin\phi}$ is large and negative in the covered kinematics (see figure 2). This amplitude relates to the imaginary part of the GPD H. The constant moment of the BSA $A_{\mathrm{LU,I}}^{cos0\phi}$ is compatible with zero, while the second sine moment $A_{\mathrm{LU,I}}^{sin2\phi}$ seems to tend towards negative values.

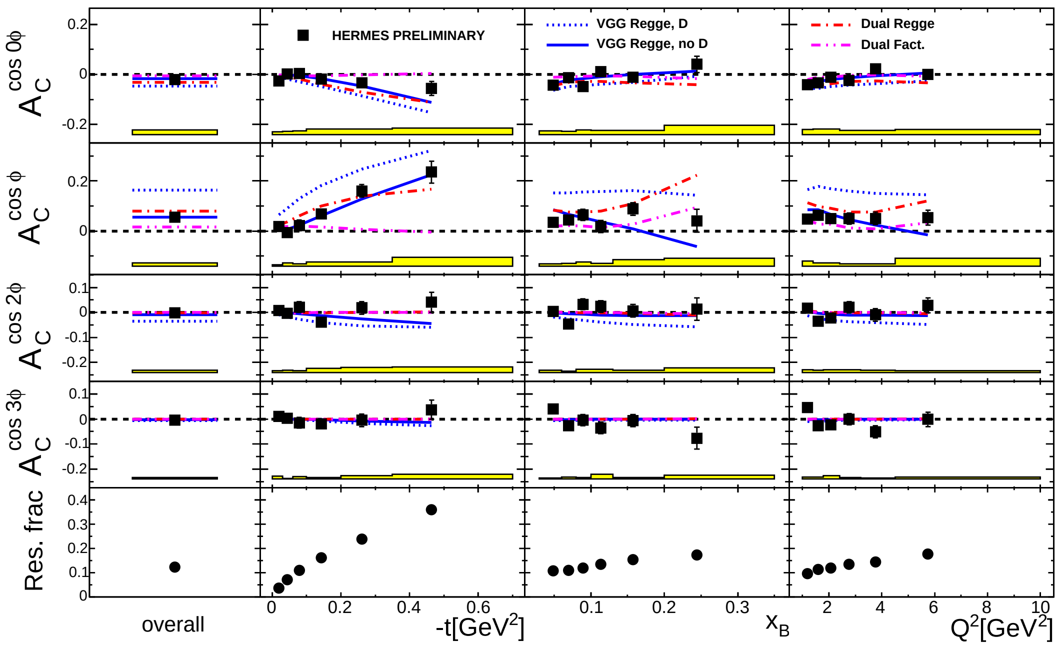

Figure 1: The BCA amplitudes extracted on a hydrogen target at the HERMES experiment. For more explanations see the text.

Also drawn in the figures are model calculations based on the framework of double distributions [9, 10] (labeled VGG) and the dual-parametrization model of [11, 12] (labeled Dual). Both models incorporate a Regge-inspired t-ansatz and a factorized t-ansatz.

The BCA amplitudes favor the models with a Regge-inspired t-dependence, if the D-term is neglected in the case of the DD-based model. For the comparison of this model to the BSA results bands have been calculated by varying the skewness dependence via the parameters b_{val} and b_{sea} . Irrespective of the chosen t-ansatz both bands miss to describe the data except for small$-t$. However, with increasing $-t$ the unknown contribution from the associated process rises up to about 35%. The dual-parametrization model describes this data very well.

To conclude, HERMES has measured a significant first cosine (sine) moment in the BCA (charge-dependent BSA) and thereby confirmed previous publications [13, 14, 7]. The statistical precision of the data allows for strong constraints on theoretical calculations, once the influence of the associated process has been pinned down. This will be possible with the data taken with the Recoil Detector.

This work has been supported by the German Bundesministerium für Bildung und Forschung (contract nr. 06 ER 143) and the European Community-Research Infrastructure Activity (HadronPhysics I3, contract nr. RII3-CT-2004-506078).

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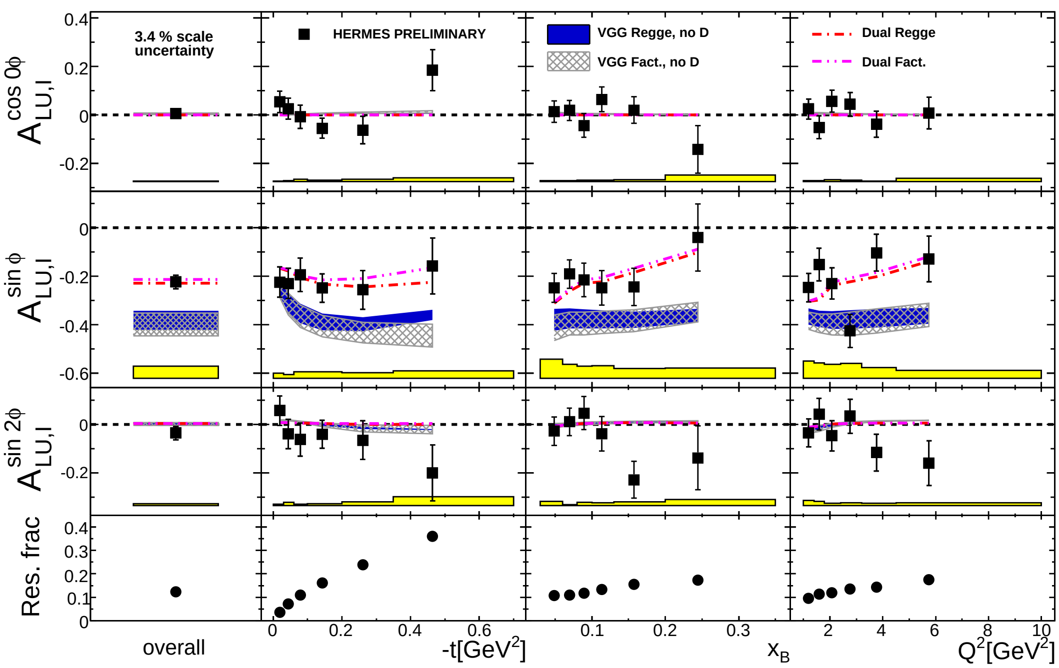

Figure 2: The charge-dependent BSA amplitudes extracted on a hydrogen target at the HERMES experiment. For explanations see the text.

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